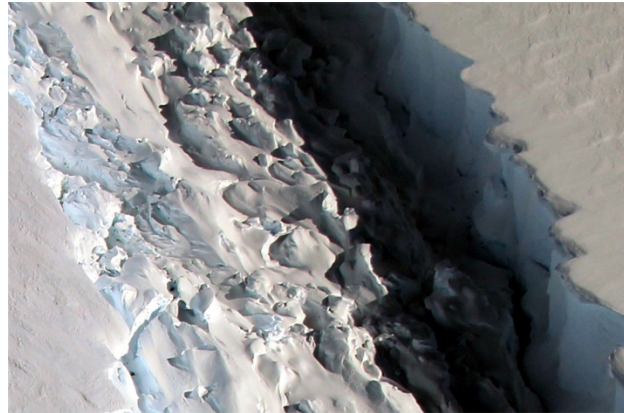


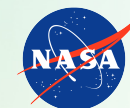
SCIENCE



Surface Deformation Change Technology Workshop Discussion Framework

Stephen Horst and Paul Rosen

May 2019



Jet Propulsion Laboratory
California Institute of Technology

Deriving Order from the Chaos

How do we talk about technology with no defined requirements?



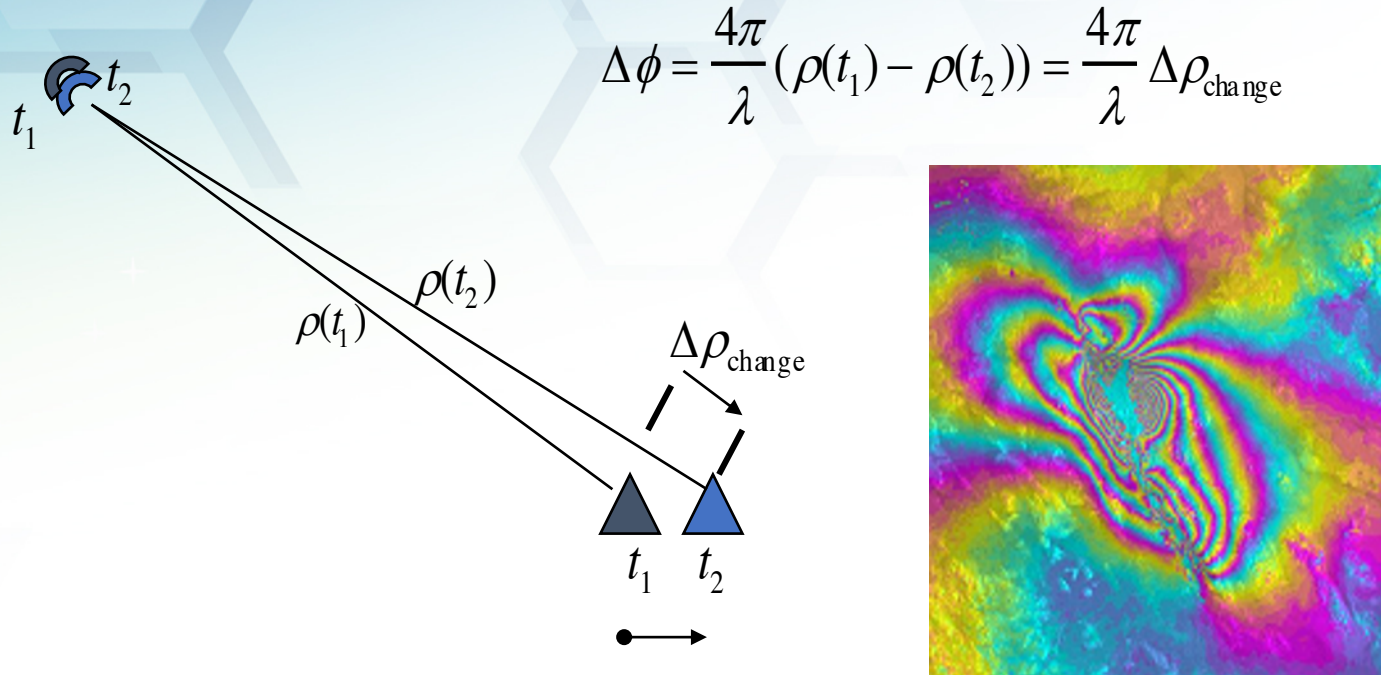
Explicit SDC Observation Goals:

- Interferometric repeat-passes at sub-weekly to daily rates.
- Resolution needs ranging from 5m to 15m
- Sensitivity to height changes between 1-10 mm
- Time series measurements from 1 mm/week to 1 mm/year
- Continuous global monitoring of all land and coastal areas
- Supplement the program of record running from 2017-2027
- Provide a plan for a 10+ year mission lifetime
- Maximum cost to NASA of \$500M (Phase A-D)

Implicit SDC Observation Goals:

- Do not optimize for pure interferometry with no radiometry
- Noise equivalent $\sigma_0 < -20$ dB
- Ambiguities < -20 dB

Repeat-pass Interferometry and Error Sources

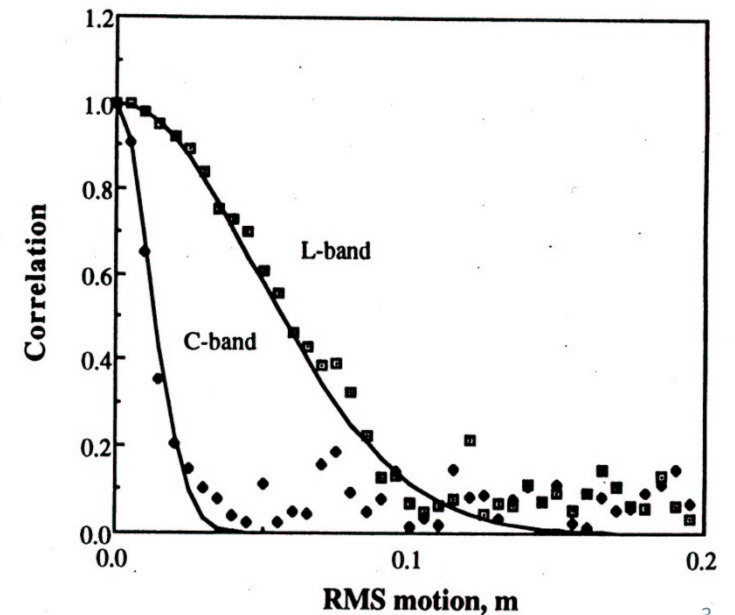


Longer wavelengths provide better foliage penetration and temporal decorrelation times

L (24 cm) C (6 cm) X (3 cm)

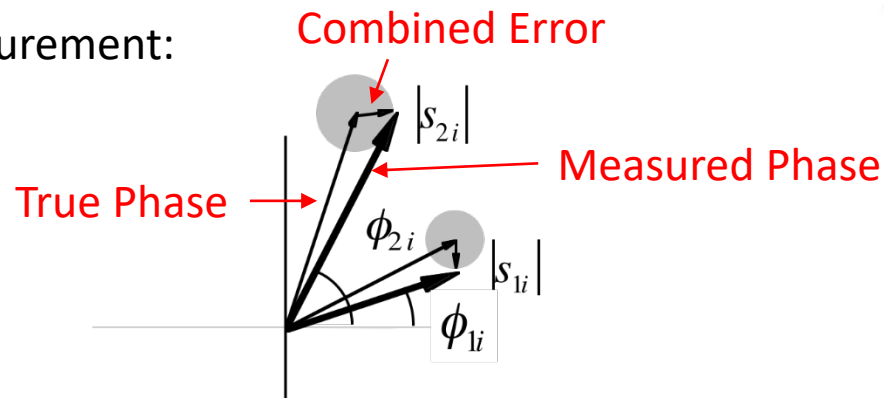


SIMULATED AND THEORETICAL MOTION DECORRELATION



Non-ideal Factors Impacting the measurement:

- Topography
- Temporal Decorrelation
- Baseline Decorrelation
- Rotational Decorrelation
- Thermal and System Noise



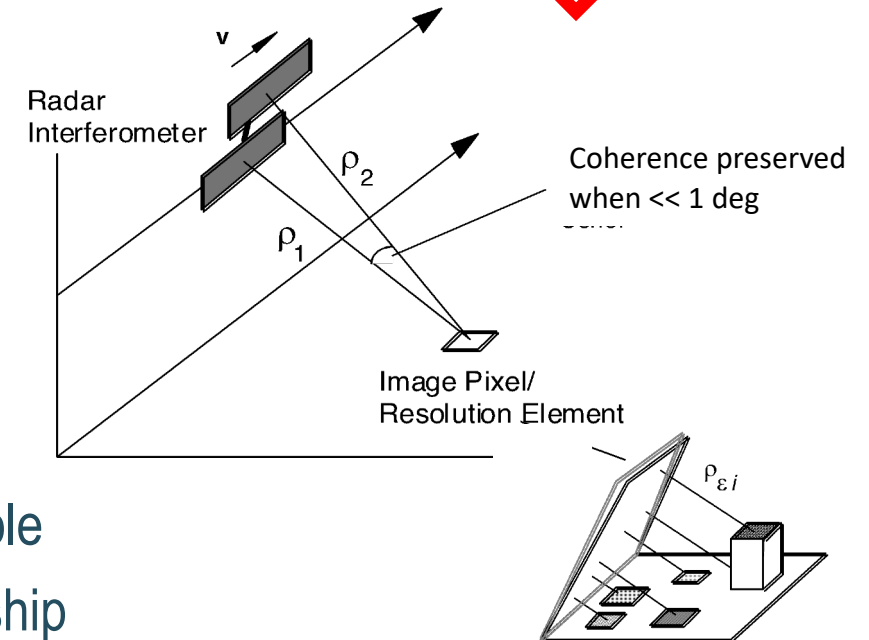
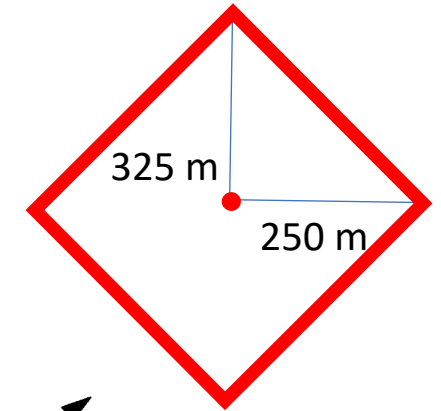
Ephemeris Objectives

- Need to fly a repeat ground track to minimize baseline de-correlation
- Produces an orbital diamond that bounds the ephemeris
 - Scales with wavelength (scatterers more sensitive to change at shorter λ)
 - Scales with altitude/look angle (Δ at closer range produce more angular Δ)
- Sun-synchronous orbits desired
 - Minimizes temporal variation at different times of day

Attitude Objectives

- SAR geodetic information is independent of attitude
- Attitude will impact rotational decorrelation
- Typically steer spacecraft to “zero-doppler” point over the orbit
- In general, pointing to within 10% of the antenna beamwidth acceptable
- Tighter requirements possible for techniques that require the relationship between time and angle to be known in real-time

Orbital Diamond for NISAR
725 km altitude at L-band



SAR Aperture Objectives

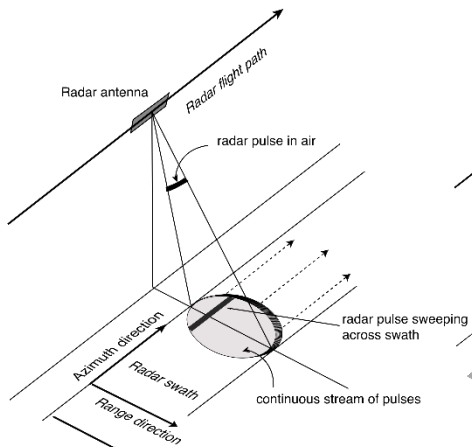
- Min. aperture area required to form a SAR image

Band	Aperture Area	Aperture Length	Aperture Width
L-band	$> 11.7 \text{ m}^2$	$< 20 \text{ m}$	$1.38 \text{ m} < W < 0.5 \cdot N \text{ m}$
S-band	$> 4.6 \text{ m}^2$	$< 20 \text{ m}$	$0.54 \text{ m} < W < 0.2 \cdot N \text{ m}$

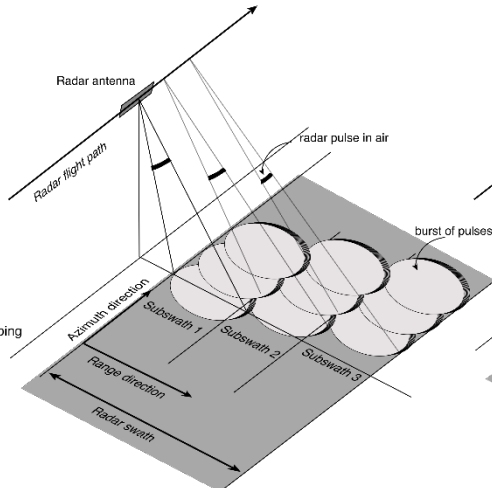
N is # of spacecraft to achieve global coverage with 7 day repeat

- Cannot achieve objectives with a single spacecraft
 - Need at least 3 spacecraft for traditional SAR
 - Could reduce to 2 with a specialty wide swath technique

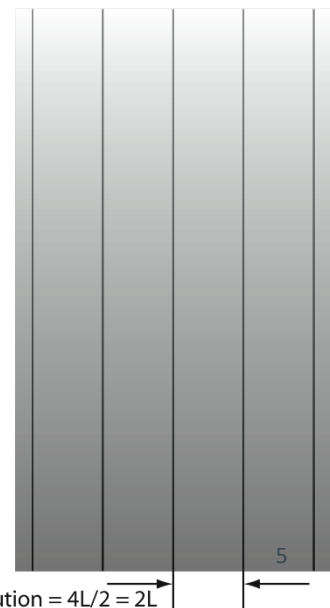
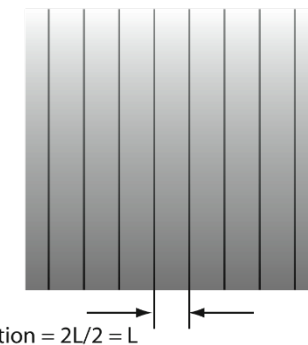
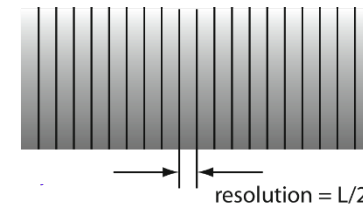
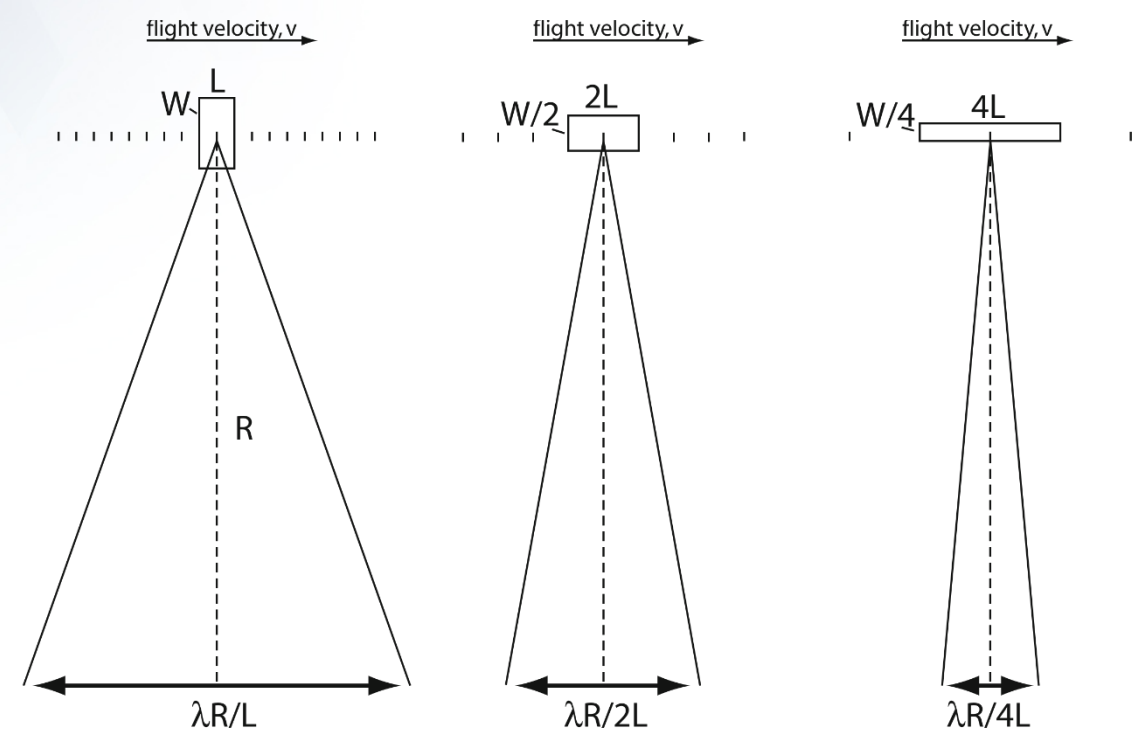
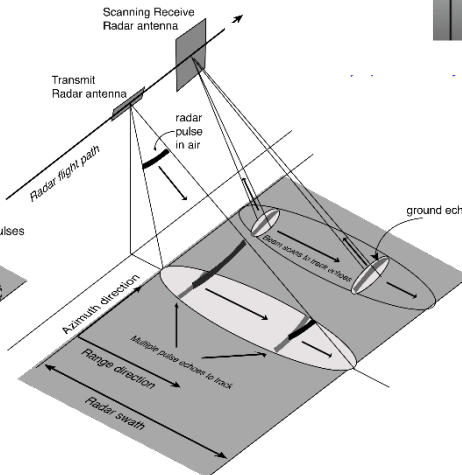
Stripmap (traditional)



ScanSAR



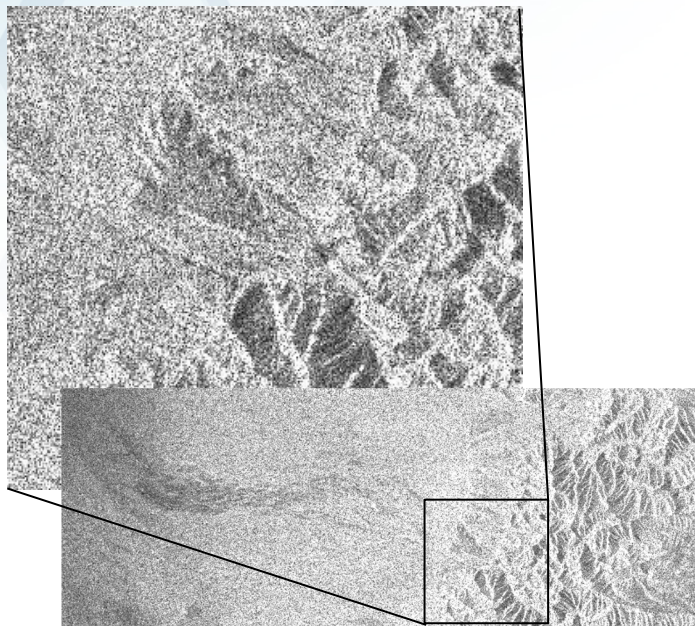
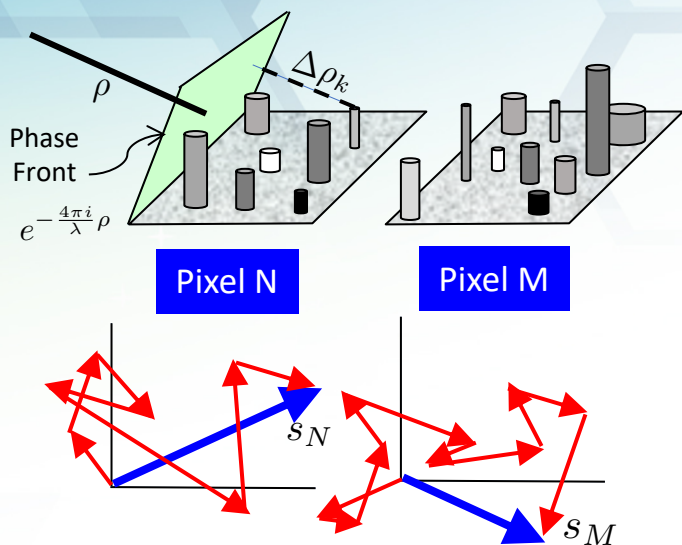
SweepSAR



$$\text{Doppler-allowable swath} = cL/4v \sin \theta$$

$$\text{Beam-limited swath} = \lambda R/W \cos \theta$$

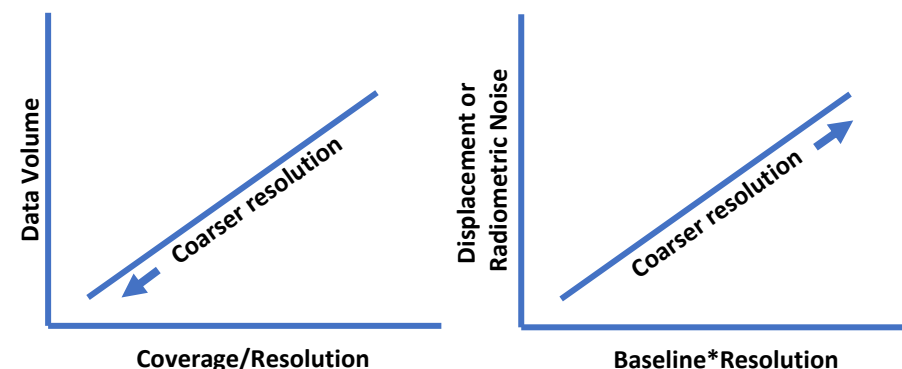
Speckle, Resolution, and Data Rate



Data Rate determined by:

- PRF
- Stored Sample Rate
- Stored Sample Depth
- Orbital Duty Cycle

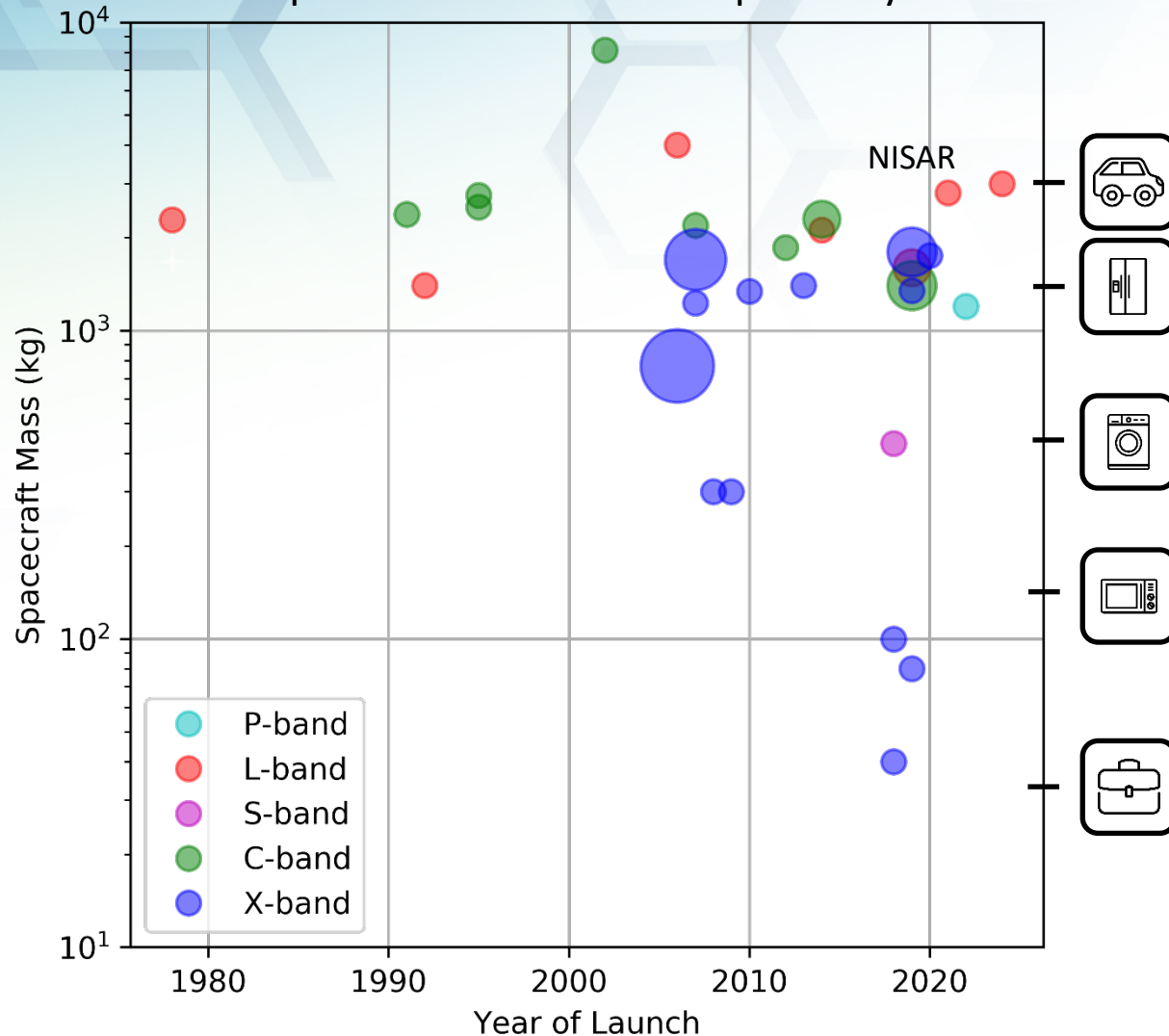
But coarser resolution also increases the speckle noise



- Full resolution SAR imagery has a grainy appearance called speckle, caused by the coherent nature of SAR imaging.
- The total signal return from a resolution cell is the coherent sum of the returns from all the individual scatterers within it that are generally randomly distributed.
- Natural speckle masks intrinsic radar backscatter which contains surface information, independent of SNR!
- Spatial averaging (looks) reduces the speckle and draws out the natural backscatter reflectivity at the expense of resolution

The Spaceborne SAR Landscape

Spaceborne SAR Landscape Today



*marker size indicates current size of constellation

The potential for data collaboration:

Sentinel-1 has agreed to cover the Arctic regions, enabling NISAR to keep a left-looking orientation and obtain a continuous time series of the Antarctic.

In order to be useful to NASA, data must be:

- Free of charge
- Open access to the public

To date, only a few systems plan to use this model on a large scale:

- Sentinel-1
- NISAR
- Sentinel-1 NG
- TanDEM-L

Could other systems meet these needs on a more limited scale?

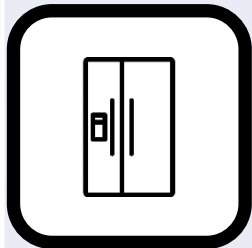
Instrument Class and Capability Descriptions



Jumbo Satellite

S/C Mass Range	DC Power	Dissipated Power	Stowed Volume	Constellation Size
2000-2500 kg	1000-1800 W	800-1600 W	~4x2x2 m ³	1-2

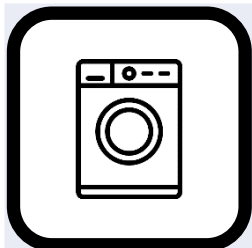
A big flagship spacecraft in the vein of NISAR, Sentinel, or ALOS. Has a wide suite of instrument modes for observation. Only one of these can be built under any reasonable budget constraints and therefore augmenting an existing observation system such as NISAR will be necessary to achieve SDC objectives. The SAR instrument is likely not the only one on-board. Implies minimal technology investment.



Large Satellite

S/C Mass Range	DC Power	Dissipated Power	Stowed Volume	Constellation Size
1000-1500 kg	500-1500 W	300-1300 W	~3x1.5x1.5 m ³	2-4

Spacecraft on the scale of TSX or RCM. The SAR instrument is the only instrument on board. Utilizes technology improvements to reduce size but still maintains a full feature set of observation modes and polarizations, with traditional radiometric performance levels. Building enough of these would allow meeting SDC goals on its own but would probably exceed the cost cap without partnerships.

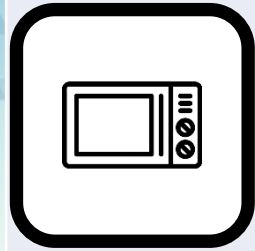


Medium Satellite

S/C Mass Range	DC Power	Dissipated Power	Stowed Volume	Constellation Size
500-800 kg	200-1000 W	100-800 W	~2x1x1 m ³	6-9

Spacecraft on the scale of NovaSAR-S. The full suite of measurement modes has been reduced somewhat, but radiometric performance of the supported modes is largely maintained and there is some room to trade-off which features stay and which go. The reduced measurement flexibility comes with an improvement in the number of observatories flown. Some thermal constraints for global coverage.

Instrument Class and Capability Descriptions



Small Satellite

S/C Mass Range	DC Power	Dissipated Power	Stowed Volume	Constellation Size
100-300 kg	100-300 W	60-200 W	~0.8x0.5x0.5 m ³	6-32

Spacecraft on the order of Iceye or Capella. Supports only a single or very stripped down set of modes and if operating on its own will have reduced radiometric performance, not necessarily a deal-breaker for interferometry. Observatories could work together to try and get back some performance improvements. Severe thermal constraints. Highly specialized objective set if used alone.



Micro Satellite

S/C Mass Range	DC Power	Dissipated Power	Stowed Volume	Constellation Size
30-50 kg	30-100 W	30-100 W	~0.3x0.3x0.3 m ³	10-100

An observatory too small to support its own full SAR radar for continuous global monitoring. Could come into play as a receive-only platform in a multi-static radar configuration. As the lowest cost option and without the complications of a transmitter, these could theoretically be produced in the hundreds if needed.



Cubesat Satellite

S/C Mass Range	DC Power	Dissipated Power	Stowed Volume	Constellation Size
5-20 kg	10-30 W	10-30 W	~0.1x0.2x0.3 m ³	30-?

An observatory too small to support its own full SAR radar for continuous global monitoring. Could come into play as a receive-only platform in a multi-static radar configuration. As the lowest cost option and without the complications of a transmitter, these could theoretically be produced in the hundreds if needed.

Possible Candidate Architectures



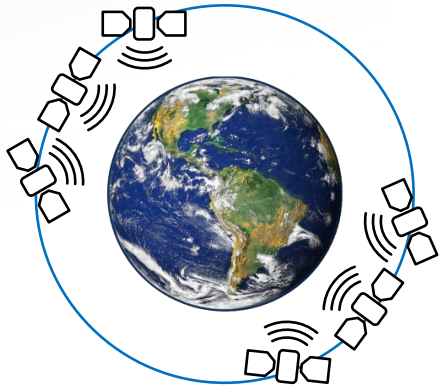
Dispersed SAR Constellation

Contains N satellites equally spaced around the orbit, where N is 3-6. Similar to RCM or CSM mission architectures.



Dispersed Wide Swath SAR Constellation

Contains 2 satellites equally spaced around the orbit. Somewhat similar to the TanDEM-L mission architecture but the observations are one half orbit separated and not working in formation.



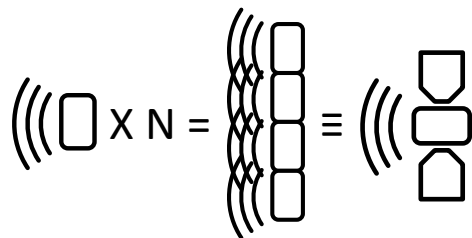
Grouped SAR Formation

Contains N groups of 3 satellites equally spaced around the orbit, where N is 2-4. Provides 3D deformation vectors and measured removal of tropospheric delay.



Distributed SAR Constellation

Contains many cheap small satellites covering smaller swaths. Total coverage area is maintained by increasing the total number of satellites.



In-Space Assembly

As an alternative to traditional deployed fixed structures, in-space assembly may offer the possibility of building larger apertures more cost-effectively.

Number of small SAR satellites to achieve NISAR-like coverage

- The appropriate metric for comparison of a **global coverage** science mission is **area coverage rate**

NISAR Swath NISAR L-band duty cycle

$$N_L = \frac{240 \times 0.5}{S \times T_o}$$

smallSAR Swath Small SAR duty cycle

NISAR S-band duty cycle

$$N_S = \frac{240 \times 0.1}{S \times T_o}$$

- Under assumptions of 10% duty cycle and 50 km swath for a small SAR
 - 24 L-band radar satellites
 - 5 S-band radar satellites
- Therefore small SARs need to be quite inexpensive to provide similar performance for global fast coverage